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# GLOBAL LAND MONITORING USING AVHRR TIME SERIES

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## ABSTRACT

Global Vegetation Index (GVI) time series of multispectral AVHRR weekly composite data with a 0.15° resolution have been collected from NOAA-9 and -11 since 1985. A prototype global land monitoring system was developed based on monthly maps of standardized anomalies of satellite derived Normalized Difference Vegetation Index, NDVI, and Channel 4 brightness temperature, $T_4$. Processing included post-launch updated calibration and cloud screening, filling in the cloud induced gaps by monthly averaging and interpolation, and suppressing residual noise by smoothing. Monthly maps were used to derive climatology, in terms of multiannual means and variability, and monthly standardized anomalies, which allow monitoring such extreme natural events as droughts and floods. However, some discontinuity and residual trends, which can still be traced in time series, preclude accurate detection of moderate ecosystem changes. Discontinuity results from the switch from NOAA-9 to NOAA-11 in 1988, and Mt.Pinatubo eruption in 1991. Residual trends can be attributed to a combined effect of satellite orbit drift and possible persistent error in calibration of solar channels. The satellite drift affects the solar and thermal IR channels through systematic variation of illumination geometry and diurnal heating/cooling of the surface and atmosphere, respectively. Examples are given to illustrate the magnitude of these effects.

## CONCEPT OF A LAND MONITORING SYSTEM FROM AVHRR

Standardized anomalies. The proposed concept is based on a comparison of the current field of variable X with its multiannual mean $\langle X \rangle$ /1/. We define monitoring as detection of anomalies of the observed quantities from that reference state $\delta = X - \langle X \rangle$. In order to quantitatively estimate the anomalies' significance, they are compared to a reference noise level, which is provided by the climatological variance around the mean, $\sigma_X^2$. Assessment of statistical significance of the anomalies as compared to the level of inherent local year-to-year fluctuations is done by considering standardized anomalies $\delta' = \delta/\sigma_X$. This concept of monitoring is hardly new and has been employed in climate studies for decades. The lack of long term satellite-based datasets is, perhaps, the main factor that prevented this method to be widely utilized in remote sensing community.

Multispectral monitoring of land. AVHRR provides global daily coverage in 5 spectral bands. This spectral information allows retrieval of many land surface parameters, e.g. leaf area index, land surface temperature, etc. Comprehensive monitoring system should make use of a complete set of these geophysical parameters derived from all AVHRR channels. Usually, only one monitoring parameter is used, e.g. NDVI, which fails to characterize the surface fully. In aggregating NDVI, individual information of solar channels is lost. Thermal IR channels can provide additional information on surface changes. For example, both droughts and floods are associated with lowered NDVI, but have different IR signatures. Using several geophysical parameters derived from AVHRR enhances the quality of detection and interpretation of statistically significant anomalies over land.

Using AVHRR Top-Of-Atmosphere (TOA) radiances for monitoring. Strictly speaking, monitoring of land surface implies the use of surface geophysical parameters. However, retrieval algorithms from AVHRR data are not always available and reliable. If one uses standardized anomalies, an equivalent approach to monitoring is based on using the surface reflectances and brightness temperatures, normalized to a common observation-illumination geometry and local time of day. Its equivalence follows from the fact that standardized anomaly of any geophysical parameter derived from AVHRR channels can be presented as a linear combination of standardized anomalies of measurements in channels as long as the anomalies are weak enough to allow expansion of appropriate functions into Taylor's series. If the angular and diurnal variabilities contribute negligibly to the variance of remote signal (e.g. when satellite orbit is stable), surface reflectances and brightness temperatures not corrected for angular and diurnal effects are also appropriate for monitoring purposes. If most year-to-year variability in the remote signal comes from surface, and atmospheric variability contributes negligibly, even TOA reflectances and brightness temperatures can be utilized for most practical purposes. Screening of cloud contamination is, however, mandatory, since the use of unscreened data may lead to misinterpretation of the results /2/. The presently developed monitoring system within the GVI project, based on calibrated and cloud-screened TOA data, is described further.

## CHALLENGES IN THE LONG TERM LAND MONITORING FROM AVHRR

Maintenance of consistent instrument performance is required for long-term monitoring and climate studies /3/. For the proposed concept, based on the TOA reflectances and brightness temperatures, stable and uniform measurement conditions are also of crucial importance. The main factors resulting in spurious anomalies are a systematic year-to-year change in sun illumination of a certain Earth target with an abrupt change at the time of switching to a new satellite /4/, and large atmospheric perturbations.

Calibration. The upward radiances of the land-atmosphere system are derived from AVHRR raw counts by special calibration procedures. In the thermal IR, on board calibration maintains consistency and high accuracy during long time intervals. In the solar channels, however, calibration is not controlled in flight. The year-to-year increase in NDVI over the Sahara -- the infamous "greening of deserts" -- during the NOAA-9 period was shown to be a result of a differential degradation of Channels 1 and 2 /5/. The latter problem has been tackled by many investigators and to the first order has been corrected for by applying the updated post-launch calibration /6/.

Satellite switch and orbital drift. The measured radiances depend upon surface and atmospheric conditions, and sun-view geometry. The year-to-year change of equator crossing time to later in the afternoon has two major consequences: 1) illumination at lower sun elevation (higher solar zenith angle) from year to year for the same target on the same calendar day of the year, resulting in different scattering and absorption effects on the downwelling atmospheric path length, and differential bi-directional reflection from nonlambertian land surfaces; and 2) temperature diurnal change and, perhaps, different shadowing, resulting in observed brightness temperature variations. Both mechanisms result in strong non-linearity in time, since the radiative transfer processes are determined to a large part by the cosine of solar zenith angle, which starts to vary very rapidly for large zenith angles.

Large-scale atmospheric perturbations. Eruptions of El Chichon in 1982 and Mt.Pinatubo in 1991, distorted the satellite signals significantly. In some regions of the globe, the impact exceeded by a few times that from natural surface variability. Thus, for the proposed monitoring system, it is important to correct for stratospheric aerosol effect in order to make time series more uniform in terms of atmospheric conditions.

## GLOBAL MONITORING BASED ON GVI DATA: POTENTIAL AND LIMITATIONS

Monthly maps with 0.15° spatial resolution for the period April 1985 - present were developed from the NOAA GVI weekly composite dataset as described in /1/. The data were calibrated using post-launch coefficients /6/ and quality/cloud screened /2/. The monthly averaged maps were bi-linearly interpolated in order to fill in cloud induced gaps, and smoothed to supress the noise resulting from some inaccuracy in the original composites and the processing techniques. Standardized anomalies of NDVI and $T_4$ ($\delta'_{NDVI}$ and $\delta'_{T4}$) were calculated from 5-year means and standard deviations at each map cell using 1985-87 and 1989-91, comprising data collected at relatively high sun and before Mt.Pinatubo eruption. The base period was restricted to the first three years of each satellite lifetime because of satellite orbit drift. No corrections for discontinuities and drifts in satellite data were applied. As a result, the generated anomalies for the last years of satellite operations (1988 and 1992-94) are unreliable in some regions of the world since they correspond to unfavorable illumination conditions and much later satellite pass time. Additionally, data for the period between June 1991 and December 1993 are contaminated by volcanic aerosol.

Extreme natural events such as the drought of 1988 and flood of 1992 in the central U.S. and major dry/moist purturbations of the land surface are clearly delineated on monthly maps of $\delta'_{NDVI}$ and $\delta'_{T4}$. Periodicity in NDVI and $T_4$ anomalies over Northeast Brazil suggests that El Nino effect could be analyzed from these data. In depth analysis is underway, and here we discuss limitations of the developed system that must be addressed to increase the monitoring potential.

Figs. 1 and 2 show time series of monthly mean NDVI averaged over two 3°x3° targets areas: 1) Brazil tropical forest and 2) Libyan desert. Even after cloud screening and post-launch calibration applied to Channels 1 and 2, there exists a decreasing trend in NDVI during NOAA-9 period, which correlates well with the change in the solar zenith angle /7/. The latter indicates a continuous change of illumination conditions for each satellite (NOAA-9 and -11) and a discontinuity between them (Fig. 1). Residual trends persist and can be attributed to a combined effect of uncorrected illumination geometry and volcanic aerosol, and possible residual error in calibration (for NOAA-11 probably due to the short time series used for deriving it -- before Mt Pinatubo eruption). These two effects are combined in a complex way that creates a net result, which is site- and season specific. The proposed monitoring system based on analysis of standardized anomalies, which emphasize any small trend, demonstrates that spurious effects are comparable with year-to-year variability, thus precluding the accurate use of the present version of the system for monitoring moderate changes, with the uncertainty increasing with satellite's aging.

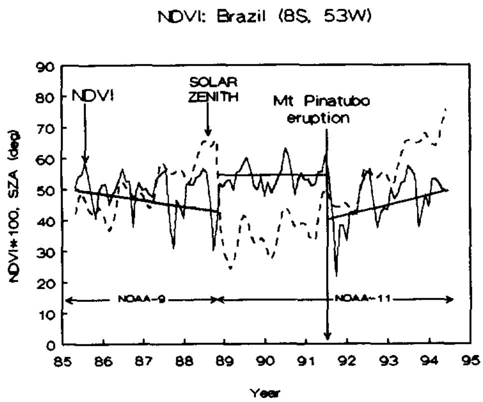


Fig. 1. The time series of monthly mean NDVI -- post-launch calibrated and cloud-screened -- over a 3°x3° tropical forest area in Brazil (8S, 53W). The trends in NDVI (straight lines) and the observational solar zenith angle (dashed curve) are also shown.

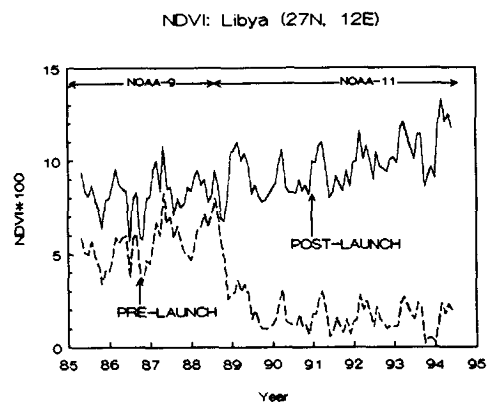


Fig. 2. Same as Fig. 1, but for Libyan desert (27N, 12E). The NDVI derived using the pre-launch calibration is also shown (dashed curve).

## CONCLUSION

A prototype system for global land monitoring based on standardized anomalies is described. It is very useful in monitoring such natural phenomena as droughts and floods. However, the monitoring potential of GVI or any other long-term AVHRR product is limited unless the spurious discontinuities and residual trends are removed in time series. Potential enhancements are described in /1/, including removal of these discontinuity and residual trends, better cloud screening, atmospheric/angular corrections, better averaging and interpolation techniques, and consideration of longer time series.
The examples given suggest that the residual trends can be of the order of the sought signal -- year-to-year change in surface conditions -- and can be mutually compensating or enhancing. Although the calibration of solar channels has been considered the most serious problem with AVHRR, we stress that, for monitoring purposes, switches from satellite to satellite and large atmospheric perturbations, as well as instability in satellite orbit may be as challenging problems as the sensor instability. Some improvements are already in progress, as, for example, pilot studies on corrections for the effect of Mt. Pinatubo. In view of the recent NOAA/NASA initiative to reprocess 12 years of AVHRR under Pathfinder project /8/, it is crucial to analyze the effect of satellite orbit drift so that necessary corrections could be developed for Pathfinder products. The NOAA-OPQ (next century) series is planned to have stable orbits and on-board solar channels calibration. However, for the Pathfinder (1981-92) and for the forthcoming NOAA-KLM period, we must deal with the aforementioned problems. It is crucial to address them now so that a reliable AVHRR climatolgy over land could be developed before the EOS era.

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